telephone even in the presence of high background noise such as found in an airport; with multiple speakers simultaneously talking into a portable speaker phone; and is free of speech anomalies and the 160ms processing delay encountered when using a synthetic voice coder which is typically employed in narrowband TDMA and CDMA systems.

F.3 B-CDMA Provides the Data Rate Desired

B-CDMA transmits 32kb/s data using a spreading code of 24Mb/s. The ratio, called the Processing Gain, is 750 and is proportional to the number of users who can simultaneously use the B-CDMA PCS channel. The processing gain is also proportional to the order of frequency diversity, which is inherent in a spread spectrum system, and hence proportional to the system's immunity to fading.

It is shown in Appendix C, that the number of 32kb/s data users in a PCS cellular system is approximately 37 percent of the processing gain, i.e.,

$$N = 0.37(750) = 280 \ users/cell^{(1)}$$

If the data rate was 64kb/s the maximum number of simultaneously active users would decrease to 140 users/cell and if ISDN rates (144kb/s) were used by each user, only 62 simultaneously active users/cell could be accommodated.

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[1]This number assumes a omnidirectional antenna. Using, for example, a 6-segment antenna, the total number of users/cell is 6 x 280 = 1700, 32kb/s data users/cell.

In practice, each user would access (and pay for) the amount of bit rate desired, so that in any cell one would have voice users as well as data users and each data user could transmit at the required data rate. We call this feature "bit rate on demand".

F.4 Relative Efficiency of B-CDMA

B-CDMA not only allows more users/cell than other technologies but does so in a spectrally efficient way.

Consider the present FDMA-AMPS system. As a result of frequency reuse, neglecting segmented antennas, and assuming 7-frequency reuse, there are only 56 AMPS users allowable/cell. The total (transmit and receive) bandwidth required for these users is 3.6 MHz. Hence the total number of users/cell/MHz is 15. However, to insure that users in one cell do not interfere with users in another (noncontiguous) cell occupying the same frequency band requires a cell spacing of about 4.8 km.

Hence the efficiency of a standard AMPS systems

$$E = 0.65\ users/km^2/MHz$$

In addition, data rates of only 1200b/s or less can be accommodated.

The efficiency of a B-CDMA system capable of operating without fading and with extremely high quality voice allows more than 500 voice users/cell (see Appendix C) with a cell spacing of 0.36 km, and occupies a (transmit and receiver) bandwidth of 96 MHz. The efficiency now is

$$E \geq 48 \; users/km^2/MHz$$

If we include in our calculation the use of a 6-segment antenna, which increases the number of users by a factor of 6; and allow additional services whose spectra overlap each other by less than 50 percent [7], which increases the total number of users by a factor of 2; the total efficiency becomes

$$E \geq 576 \; users/km^2/MHz$$

If, in addition, poor quality voice using a synthetic voice coder (called a CELP), operating at 13kb/s (with FEC) is employed[2], the efficiency now increases to

$$E \geq 1400 \; users/km^2/MHz$$

F.5 Summary

The use of Broadband-CDMA can result in high quality voice, no fading or dropped calls, data rate on demand, and the needed capacity to serve the needs of the US users at business, play or in the home. To the best of our knowledge, no other technology can display the combination of capacity and performance that B-CDMA does. The capacity of

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[2]Such coders are proposed for use in narrowband-CDMA and TDMA systems.

the B-CDMA system can be significantly greater than that obtained by AMPS and therefore efficiently utilizes the spectrum.

In addition, as discussed in SCS' comments, this high capacity and high performance can be achieved even while sharing the spectrum with the existing fixed microwave users.

APPENDIX C

COMPARISON OF BROADBAND CDMA

IN THE CELLULAR AND

PERSONAL COMMUNICATION

SERVICES BAND

COMPARISON OF BROADBAND CDMA IN THE CELLULAR AND PERSONAL COMMUNICATION SERVICES BANDS

INTRODUCTION

Bandwidth is the most important parameter of a CDMA system. It is governed by the system chip rate and affects:

- Capacity
- Fade Margin
- Data Rate
- Voice Quality
- Performance In Indoor and Outdoor Environments
- Transition Plan: Blocking Probability of AMPS Users Remaining On System
- Frequency Management
- Overlay Capability
- Adaptive Power Control

In Section 1 we discuss how each of these parameters are effected by the choice of bandwidth. In Section 2 a comparison is made between the capacity of a B-CDMA system in the Cellular and PCS bands. Section 3 presents our Conclusions.

1.0 EFFECT OF BANDWIDTH ON B-CDMA PERFORMANCE PARAMETERS

1.1 Capacity

The CAPACITY of a CDMA system is directly proportional to the ratio of the bandwidth B and the coded data rate, f_b.

Thus, the capacity increases as B increases.

1.2 Fade Margin

The received signal generally consists of delayed versions of the transmitted signal. These are the multipath signals. Those delayed versions of the signal that arrive within a chip duration and subtract, cause the received signal to "fade". Those multipath signals arriving outside the chip duration result in an increase in the interference level, since these components look like additional CDMA signals, however, they do not produce fading.

The fade margin is inversely proportional to the bandwidth, i.e., the wider the bandwidth, the smaller the chip duration and the fewer the multipath components that fall within a chip duration. Hence, the probability of a frequency-flat fade increases as the bandwidth decreases.

Figures 1.1 through 1.6 present the fade probability and fade margin as a function of bandwidth for the bandwidths 48, 30, 22, 11, 2MHz and CW. These experiments were

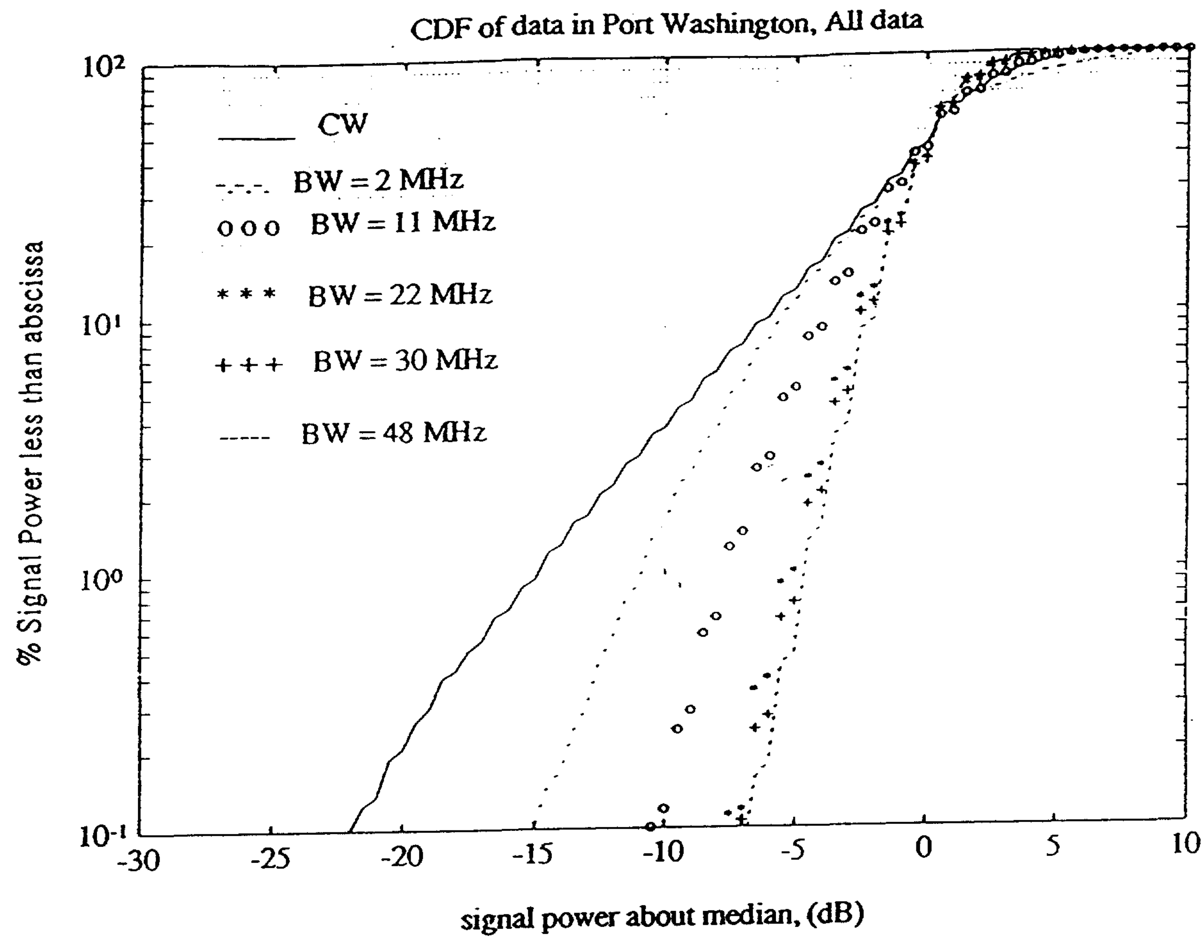
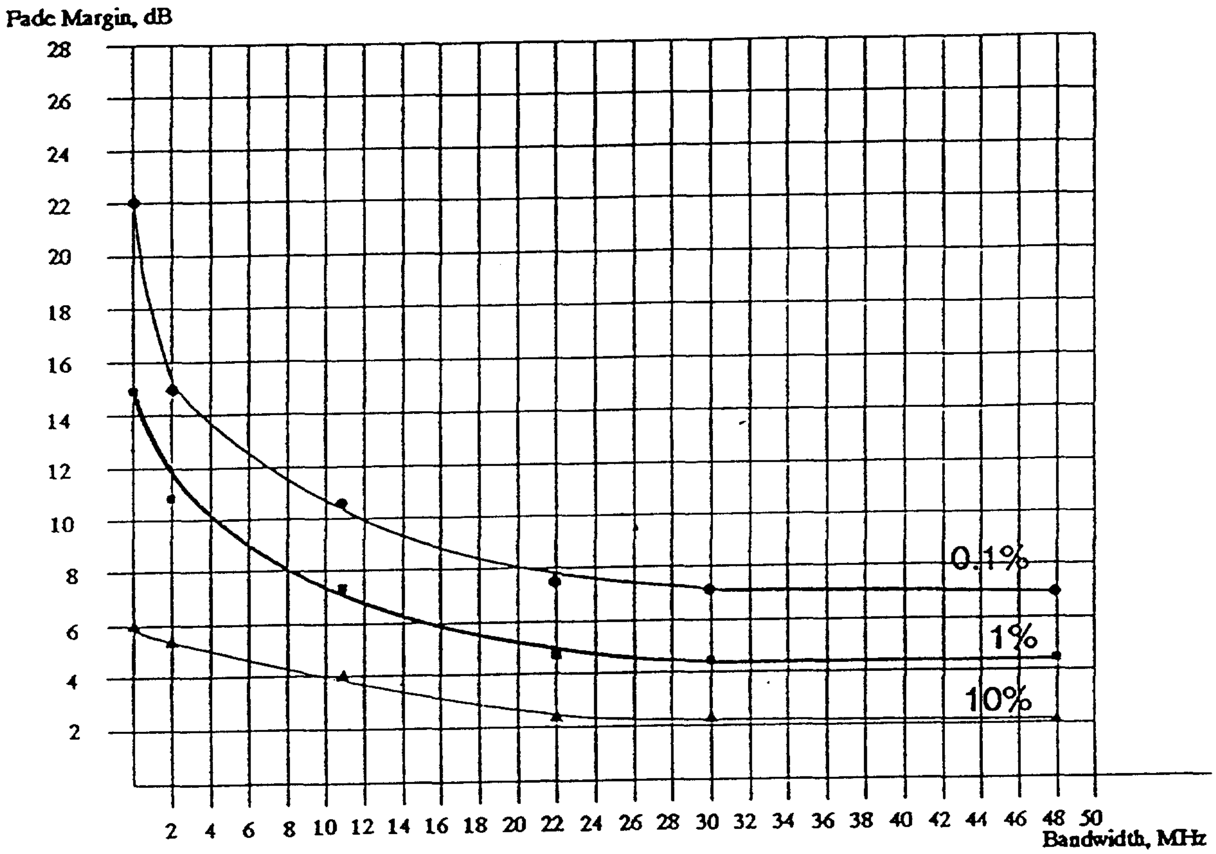

CDF of data in Port Washington, All data
CW
BW = 2 MHz
BW = 11 MHz
BW = 22 MHz
BW = 30 MHz
BW = 48 MHz
% Signal Power less than abscissa
signal power about median, (dB)
-30
-25
-20
-15
-10
-5
0
5
10

FIGURE 1.1



FADE MARGIN IN PORT WASHINGTON

FIGURE 1.2

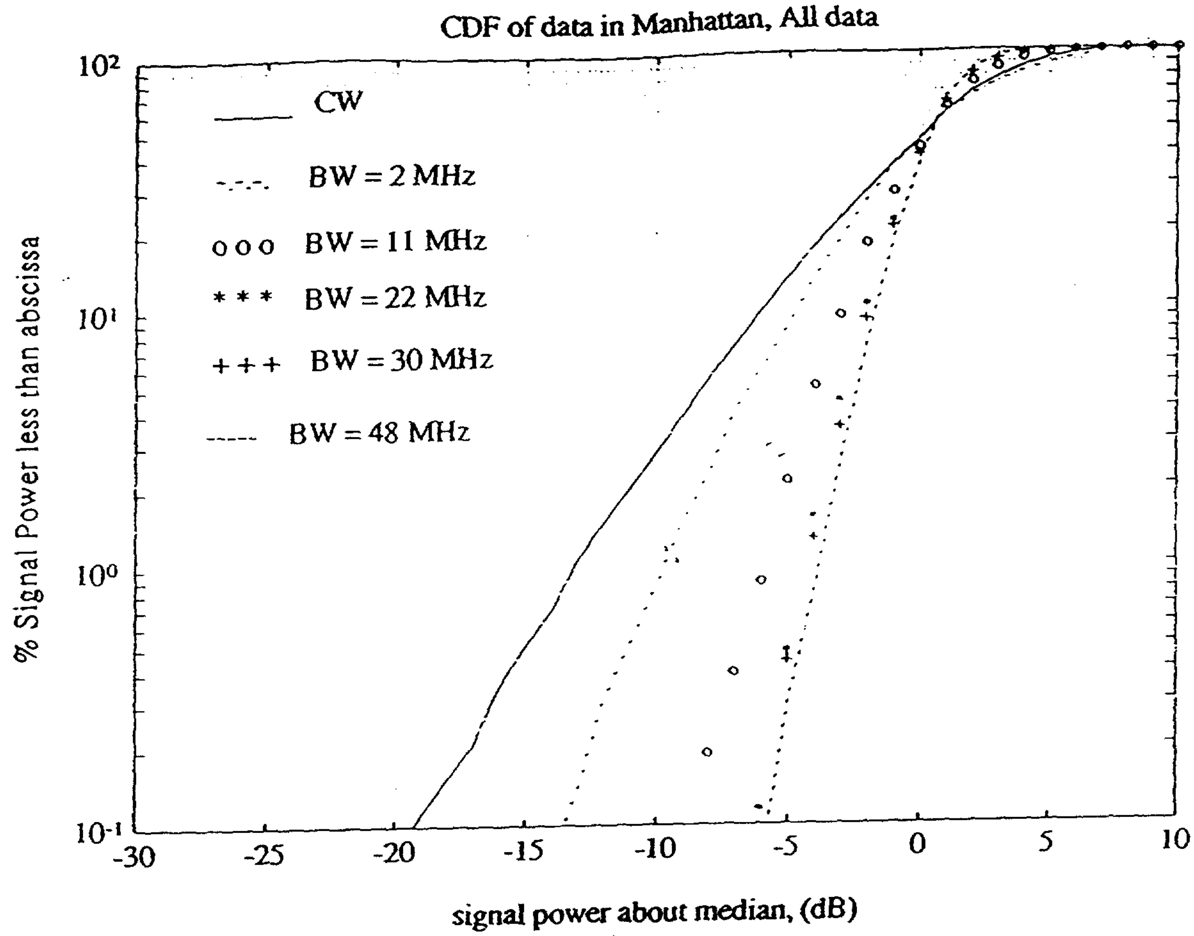
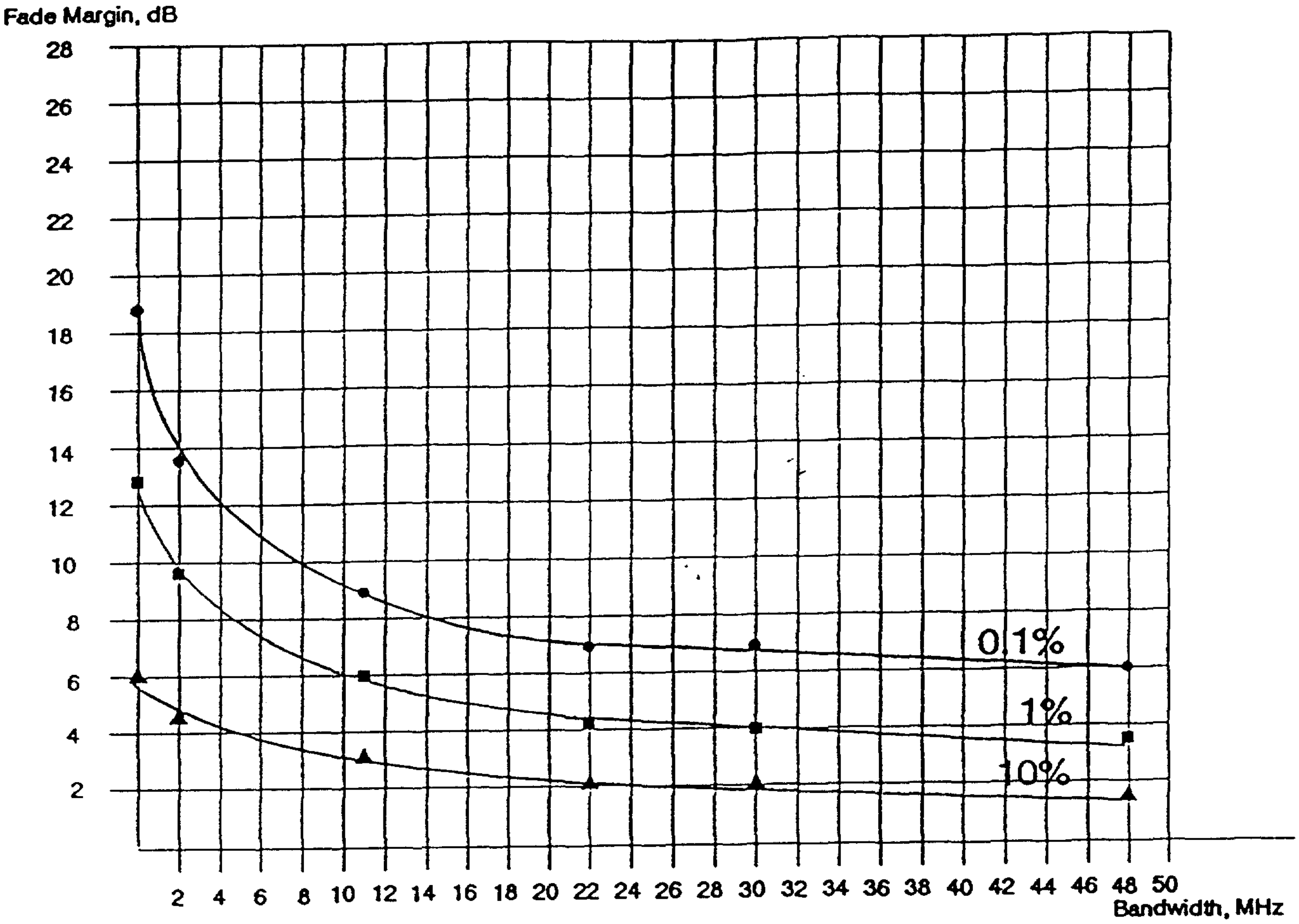
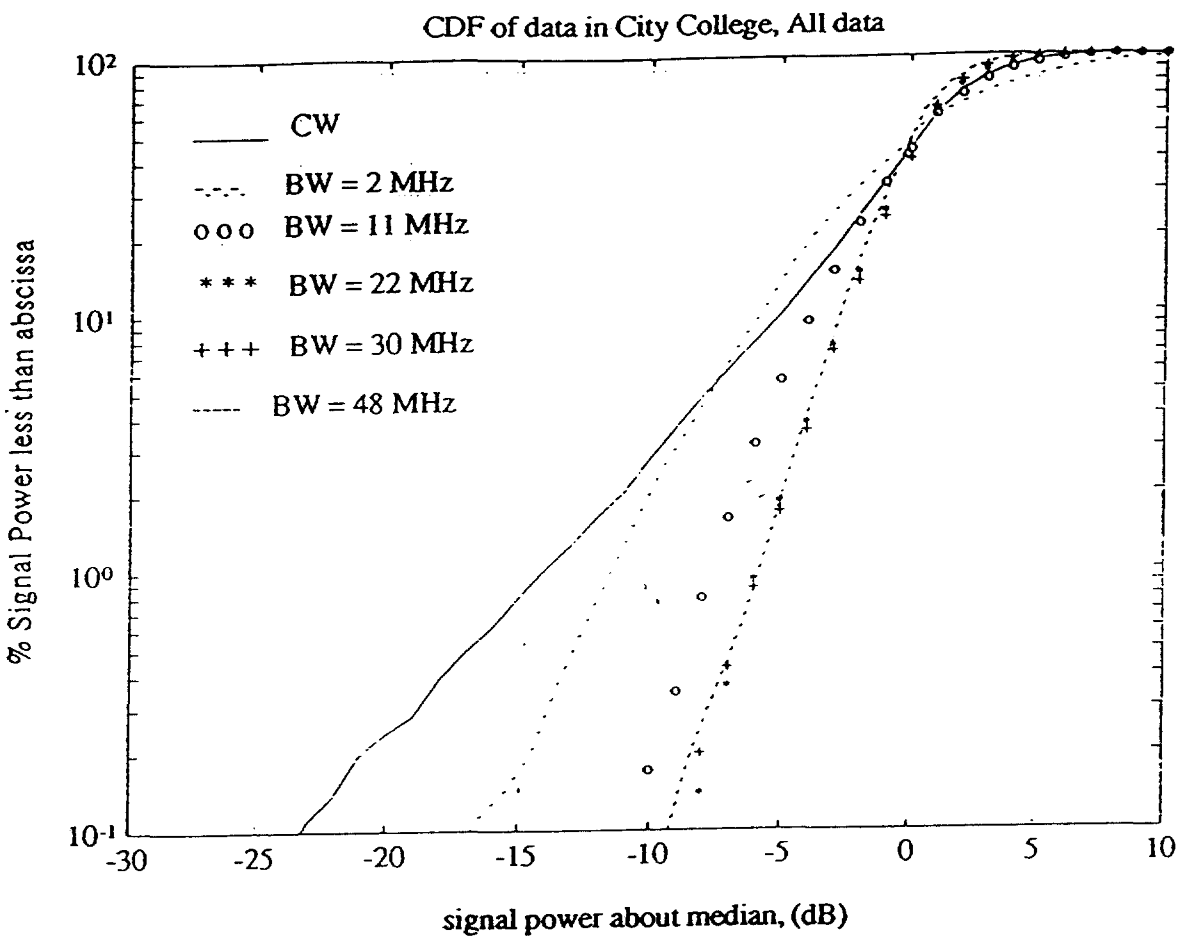

CDF of data in Manhattan, All data
CW
BW = 2 MHz
o o o BW = 11 MHz
* * * BW = 22 MHz
+ + + BW = 30 MHz
BW = 48 MHz
% Signal Power less than abscissa
signal power about median, (dB)
10^2
10^1
10^0
10^{-1}
-30
-25
-20
-15
-10
-5
0
5
10

FIGURE 1.3



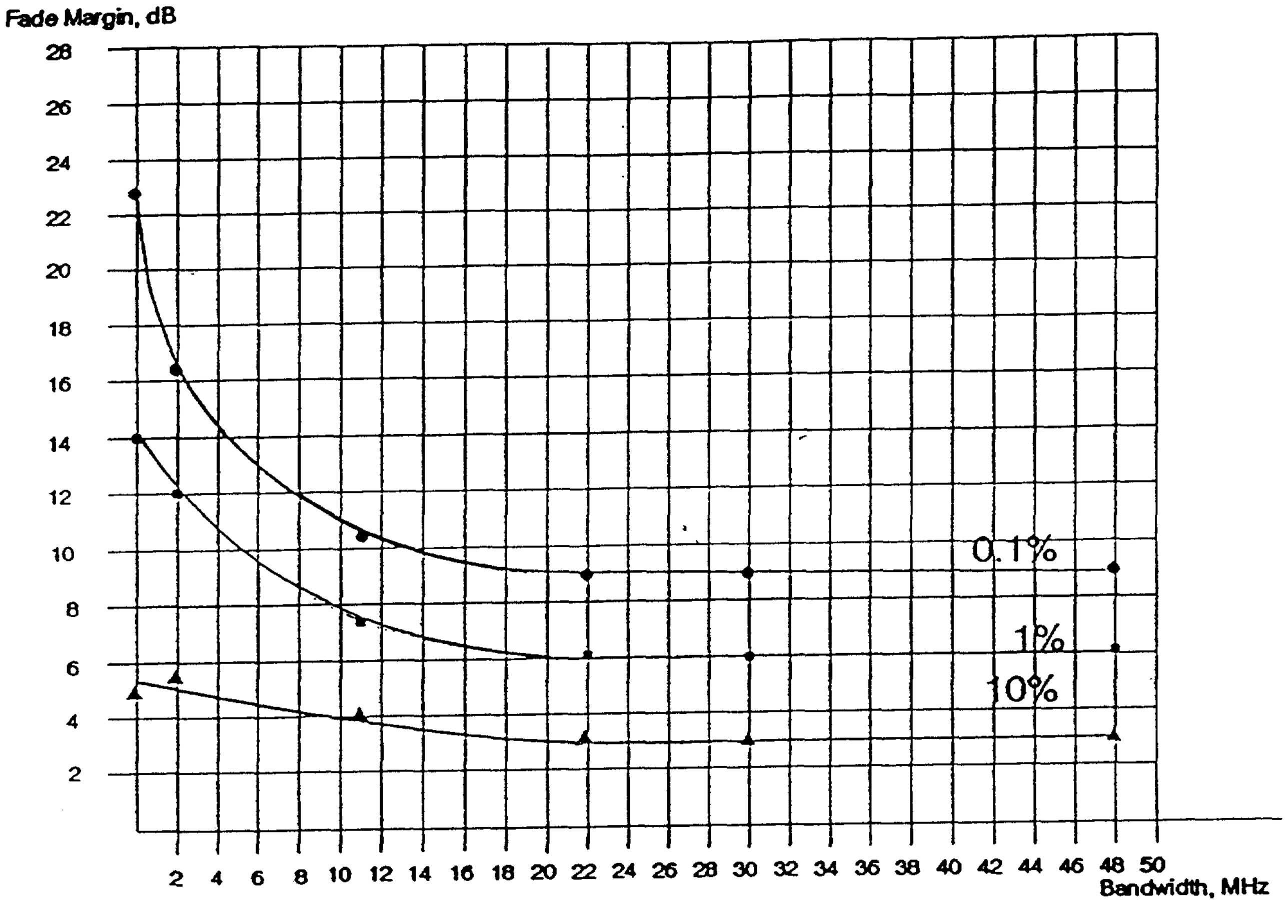
FADE MARGIN IN MANHATTAN

FIGURE 1.4



CDF of data in City College, All data
CW
BW = 2 MHz
BW = 11 MHz
BW = 22 MHz
BW = 30 MHz
BW = 48 MHz
% Signal Power less than abscissa
10^2
10^1
10^0
10^{-1}
-30
-25
-20
-15
-10
-5
0
5
10
signal power about median, (dB)

FIGURE 1.5



FADE MARGIN IN CITY COLLEGE

FIGURE 1.6

performed in an office, in the suburbs and in downtown New York City. Note the increase in the depth of fade, denoted "fade margin", as a function of bandwidth. Note particularly that the fade margin varies only slightly for bandwidths exceeding 11MHz.

Figures 1.7 through 1.12 show the results obtained when using a RAKE receiver to search different time delays for multipath. These experiments were all performed in suburban environments in which the transmitter and receiver were not within line-of-sight of one another. Figures 1.7 and 1.8 show the close-in multipath. Note that each pulse is 20ns in duration and that the extent of the multipath is typically less than 120ns. Note also that the power in the multipath is about 6dB below the largest returned signal. Figures 1.9 and 1.10, as well as Figs. 1.11 and 1.12 show additional photographs, using an extended RAKE which views the signal for $\pm 3\mu s$ about the locked signal. Note that there were no strong far-out multipaths observed.

Figures 1.13 through 1.16 show the results of a theoretical model used to model out-of-sight communications. The details are contained in appendix A.

The figures present the received multipath signals and their delays as a function of angle (0 degrees is the center of the street - See Appendix A). Each pair of figures represents a different distance into the street. While this model was originally used to predict the received out-of-sight power level as one turns a corner and moves down the street it can also be used to study the multipath components. Note that the large amplitude

Transmitter And Receiver Are
Out-of-Sight Of One Another

500 ns Full Scale
20 ns Each Dwell

FIGURE 1.7

FIGURE 1.8

Transmitter And Receiver Are
Out-of-Sight Of One Another

Scale: 5μs

FIGURE 1.9

Expanded
Scale: 500ns

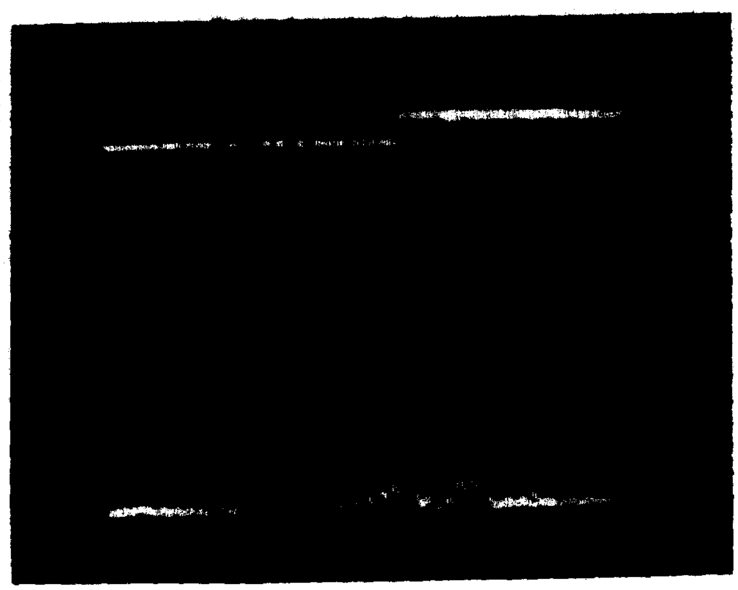


FIGURE 1.10

Transmitter And Receiver Are
Out-of-Sight Of One Another

Scale: 5μs

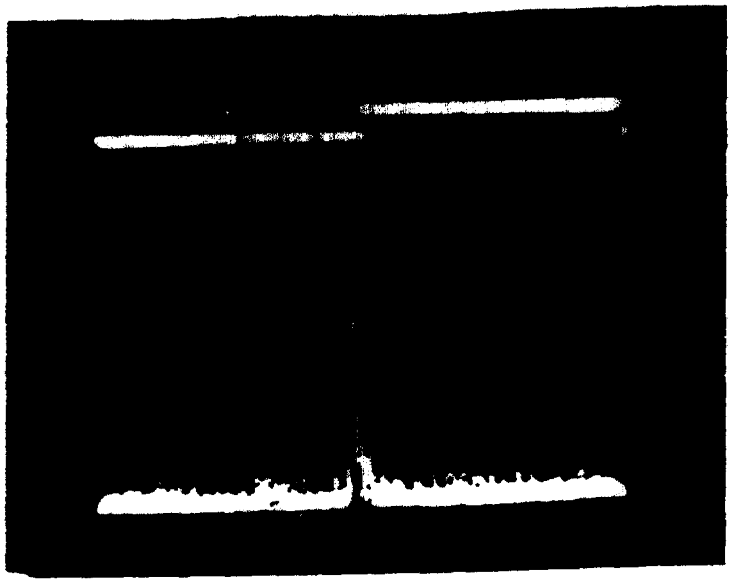


FIGURE 1.11

Expanded
Scale: 500ns

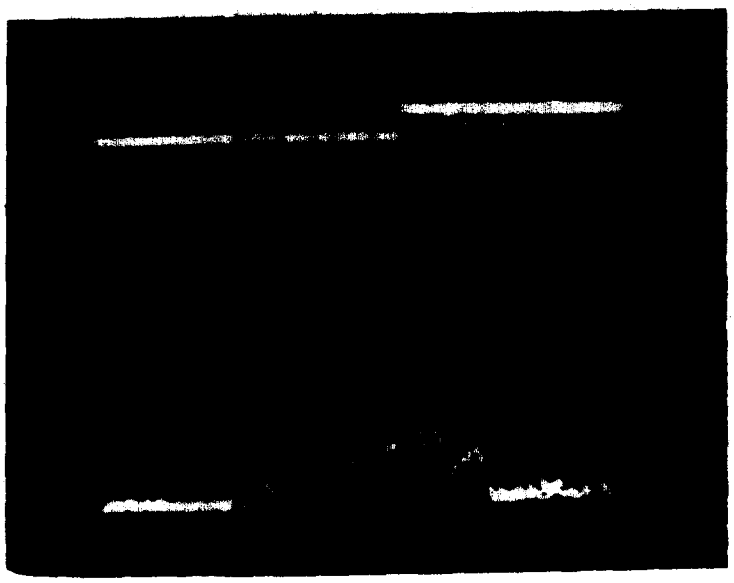
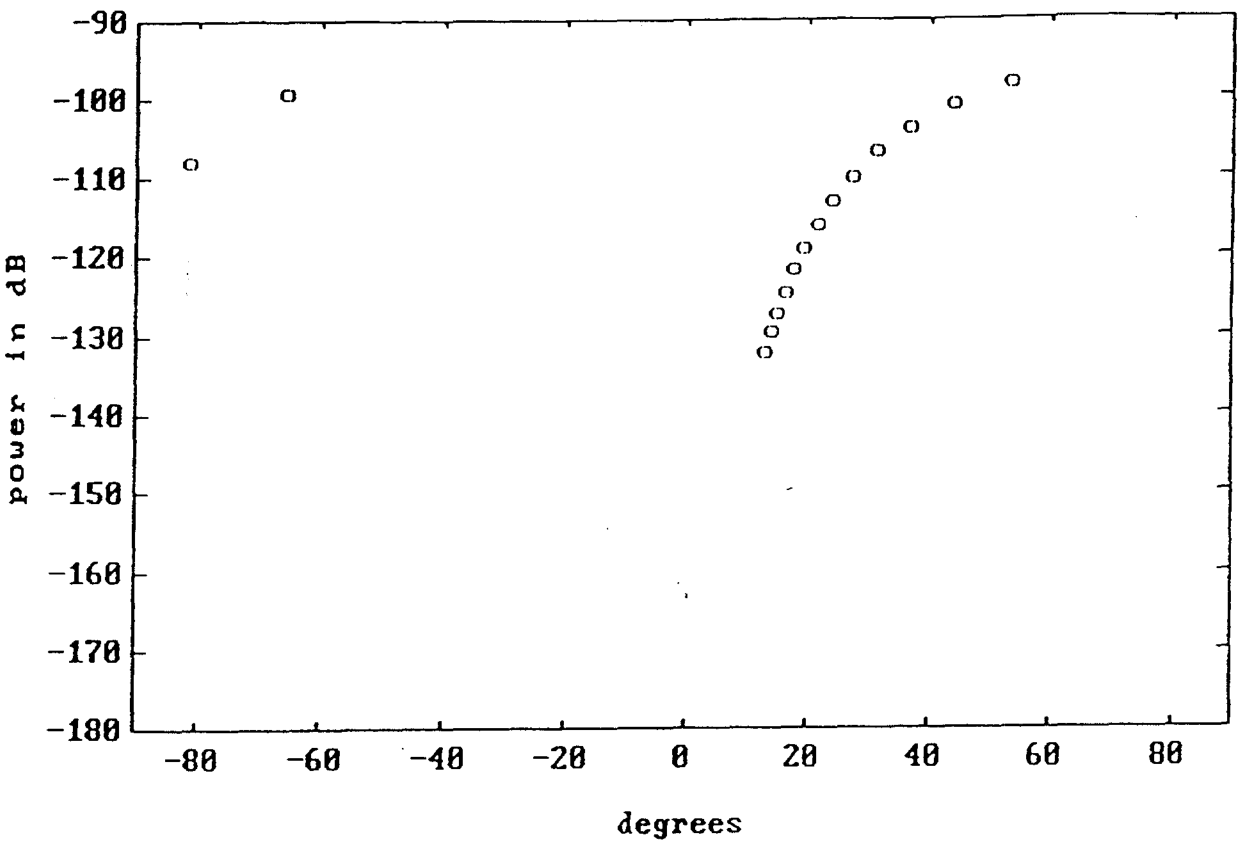


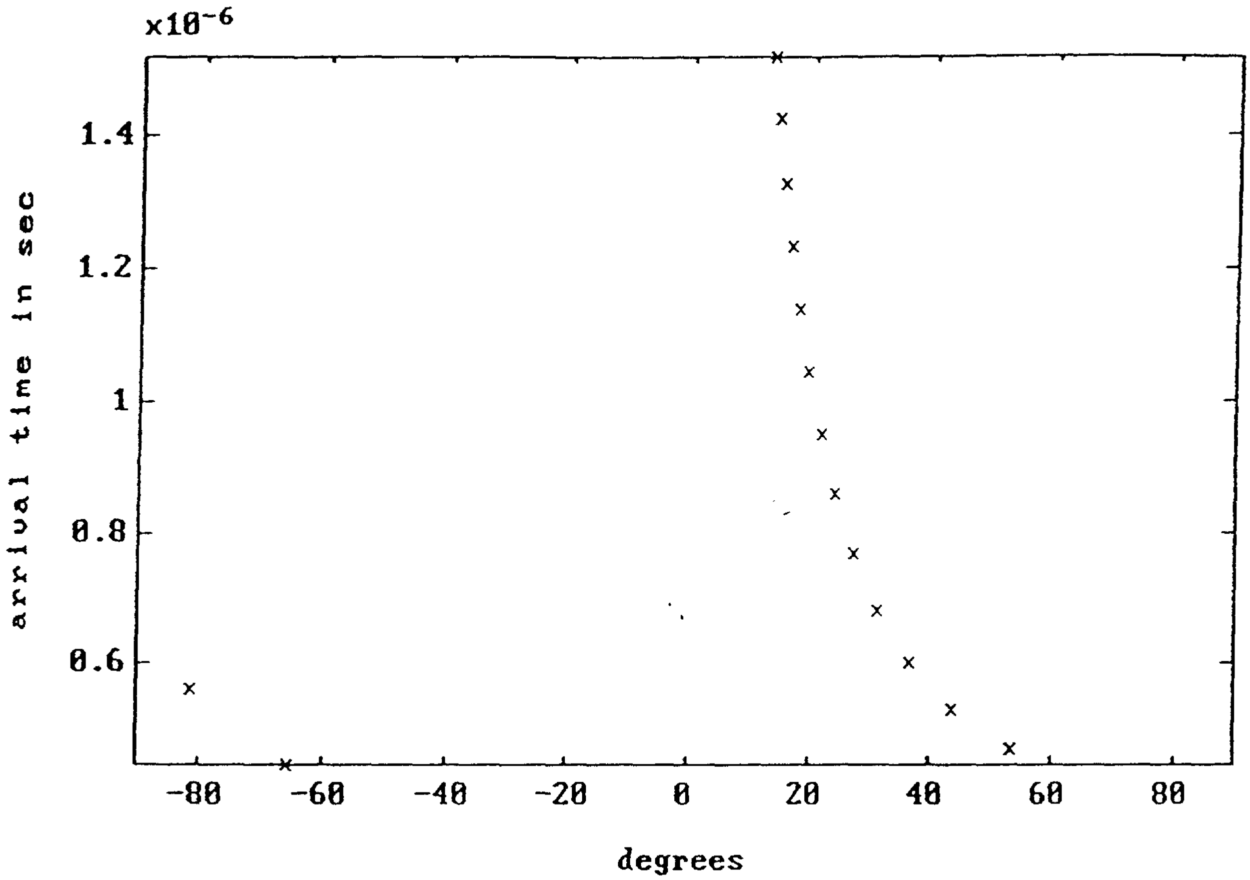
FIGURE 1.12



d_1 = 100 meters

d_2 = 10 meters

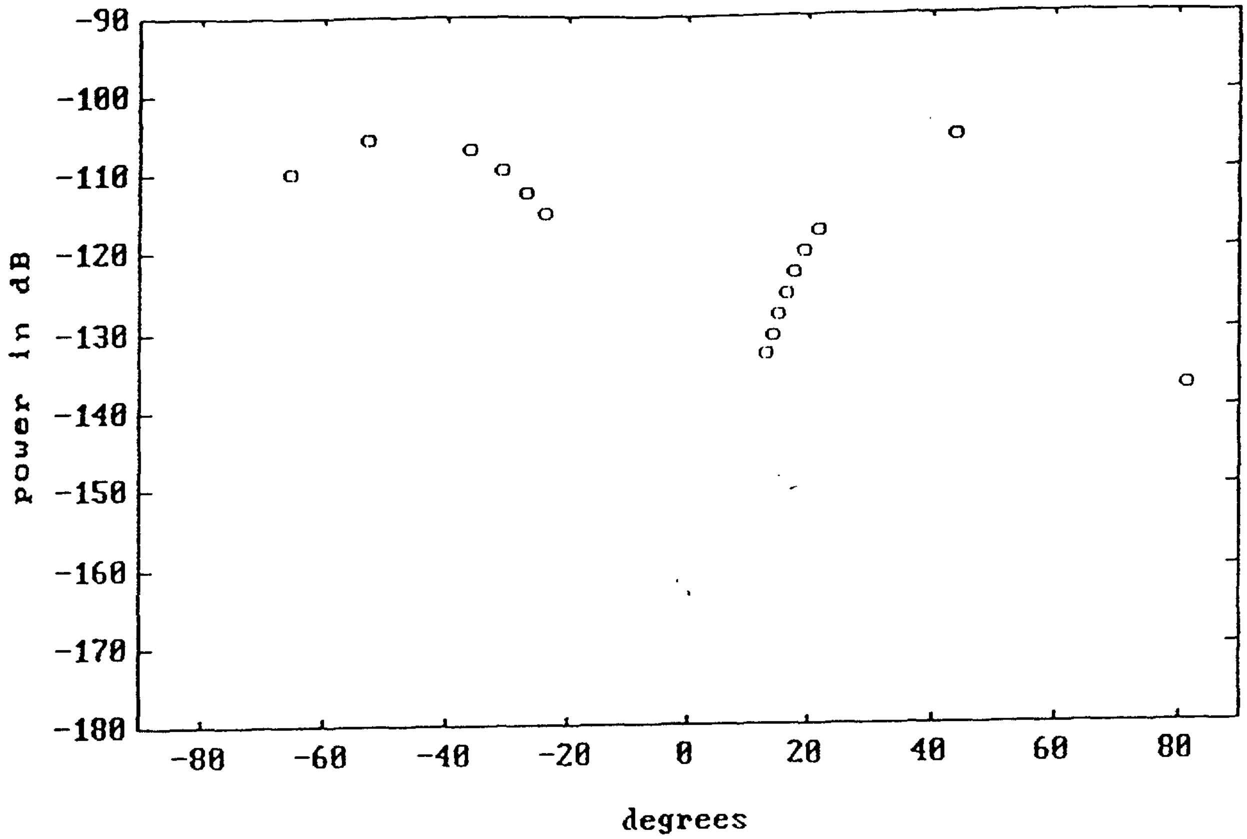
FIGURE 1.13



$d_1 = 100$ meters

$d_2 = \ \ 10$ meters

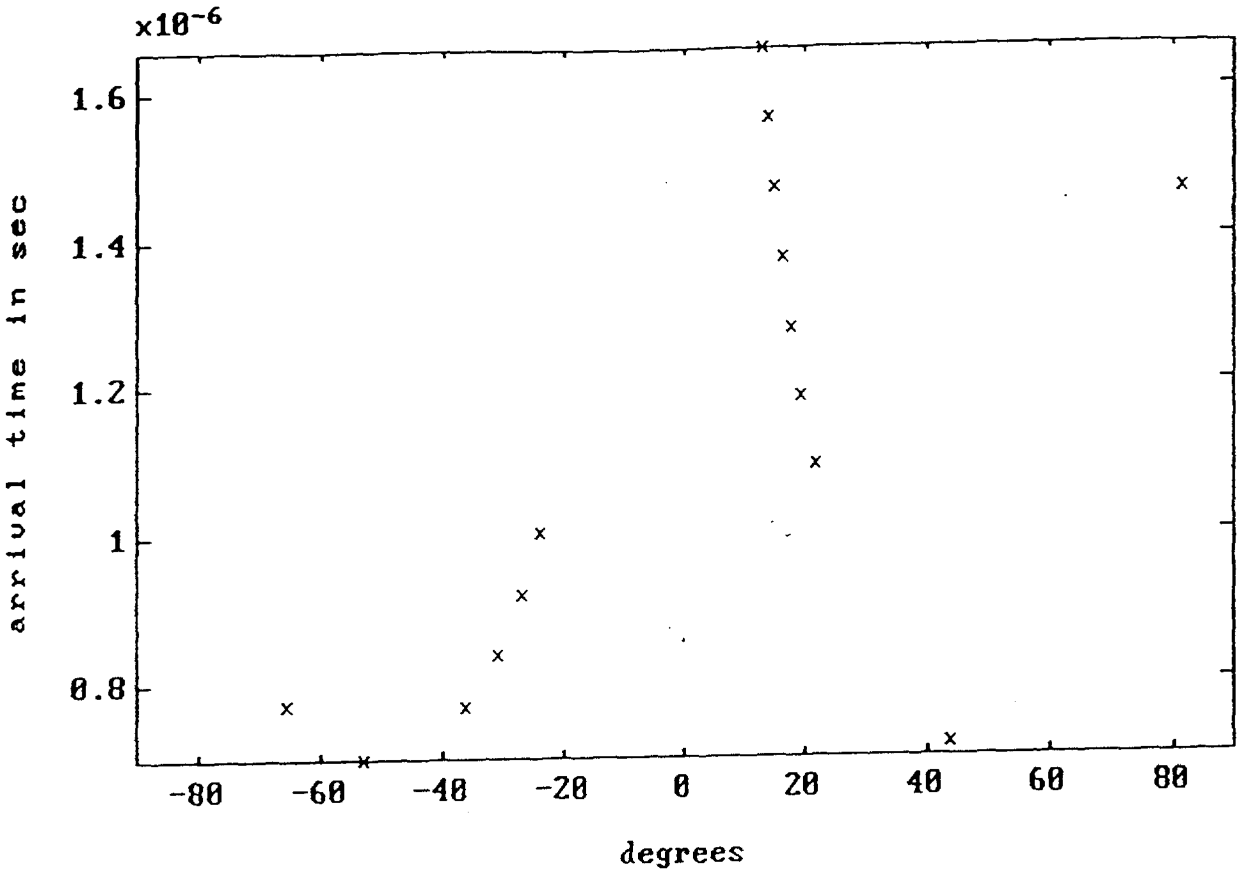
FIGURE 1.14



$d_1 = 100$ meters

$d_2 = 50$ meters

FIGURE 1.15



$d_1 = 100$ meters

$d_2 = 50$ meters

FIGURE 1.16

components are delayed by less than 100ns with respect to one another (resulting in fading) and that the relative delay between the large and small amplitude components are delayed by more than 100ns, producing no fading but some interference. However, in a narrowband-CDMA system having a chip duration of 1 μs, many more terms are present to produce fading.

Summarizing, we find that wider band CDMA systems suffer less fading. A result of this is that "far-out" multipath components are most likely to be smaller than the primary signal component. The need for a RAKE therefore diminishes as the bandwidth increases and at 10MHz there is little need for a RAKE receiver. (Of course, a RAKE receiver could be used to further enhance the performance of a wideband CDMA system.)

1.3 Data Rate

The wider the bandwidth, the higher is the data rate for the same processing gain. As the need for ISDN compatibility and multimedia transmission increases the wider the bandwidth must be.

For example, a 1MHz bandwidth signal cannot transmit 256kb/s data, which is a desired ISDN rate. The reason for this is that since there are only 4 chips per bit, there is no longer an ability to support CDMA; whereas, at 10MHz, the wideband CDMA system can still support up to 25 users in an overlay mode and up to 170 such users without the overlay.

1.4 Voice Quality

Narrowband CDMA systems require the use of synthetic voice coders in order to achieve a low data rate which is needed to obtain a reasonable channel capacity. However, while significant strides have been made in improving the quality of voice coders, they suffer from some serious defects:

- Processing Delay - Processing delays of 80ms and 160ms result. As a result, mobile-to-mobile communication has delays which can exceed that of a satellite communication link where voice delays have proven to be particularly disturbing.

- Effect of Background Noise or Music - synthetic voice coders model the human voice producing structure. Hence, communication in a strong background noise environment or for the transmission of music is not of acceptable quality.

Wideband CDMA allows a higher data rate. This means that a high quality voice digitizer, such as ADPCM or ADM, can be employed at either 16 or preferably 32 kbps. Although there is a decrease in capacity at the higher, 32kb/s, data rate, the service can be sold as a premier service and billed accordingly. In addition, a 32kb/s voice processor is less costly and draws significantly less battery power than the vocoder.

1.5 Performance

For indoor or for outdoor environments such as a central city area, beyond line-of-sight communication is the normal mode of transmission. However, the multipath being received from distant objects will typically be strongly attenuated. As a result the significant multipath signal components will not be delayed by long distances and the narrower band CDMA system will typically suffer increased fading.

To counteract this degradation in performance, it has been argued that the base should transmit two delayed versions of the signal (a delay exceeding the chip duration). Such an approach reduces the system capacity by 3dB. In addition, this is a costly solution. The correct remedy is to use a wider bandwidth CDMA system.

1.6 Transition Plan

Cellular Band

A narrowband CDMA system requires that a "chunk" of AMPS users be removed in order that the CDMA system be installed. This results in the remaining AMPS users having a higher probability of blocking. In addition, some service providers will not want to remove equipment that has not yet been depreciated and/or is in good working condition.

This problem does not arise with a wideband CDMA system which can overlay the existing AMPS service without perceptible degradation. The detailed calculations are presented in Appendix B.

PCS Band

The B-CDMA system can also overlay the fixed service microwave users located in the PCS band of 1.9GHz. The achieve this end and insure that the microwave users performance will not degrade beyond that specified by EIA Document 10E, SCS invented "Dynamic Capacity Allocation" (patent pending). Using this technique, a change in the microwave signal-to-noise ratio (SNR) results in a load adjustment in the PCS system to maintain a SNR exceeding that required by 10E. Details of this technique are described in Appendix C.

1.7 Frequency Management

A narrowband CDMA system is frequency channelized. Therefore a CDMA user on one frequency, moving into a cell in which that frequency is already fully loaded, must change frequencies in a similar way as an AMPS system. Also, as additional narrowband frequency blocks are added, this frequency block must be taken out across the entire region to avoid jamming the AMPS users, or else very careful frequency planning is needed, which still remains an issue. As each new block is added it will be lightly loaded, and therefore not efficiently used, resulting in a significant loss of AMPS users.

A wideband CDMA system is not frequency channelized and uses the entire bandwidth. Hence frequency management is not needed.